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Investigation of Natural Composites Matoa Tree Wood as the Base Material for Eco-Friendly House Piles using Ansys

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Abstract

Composite materials, in simple terms, are materials that have a multi-phase system composed of reinforcing materials and matrix materials. Composite materials are divided into two types, namely synthetic composite materials and natural composite materials. Wood is a natural composite material consisting of a reinforcement and a matrix. The wood of the matoa tree (Pometia vinnata) is known for its good mechanical strength. The comparison of compressive mechanical strength in this study was conducted on matoa wood and ironwood tree wood (eusideroxylon zwageri). This was performed as supporting data in the discussion of natural composite materials of matoa tree wood as the foundation for environmentally friendly house piles. FEM (Finite Element Method) is a numerical method that analyzes the compressive strength of retaining walls. In this study, the 2D analysis used to determine the compressive strength of the natural composite material of Matoa tree wood. In this study, Matoa wood and ironwood were analyzed for compressive strength using FEM. In this research, three different finite element numbers are based on the software. The Ansys software is used to simulate compressive strength. The results obtained were matoa wood and ironwood, respectively A1 = 6.07e^(-07) MPa, A2 = 1.11e^(-06) MPa, and A3 = 2.09e^(-06) MPa and B1 = 1.17e ^(-06) MPa, B2 = 2.13e^(-06) MPa, and B3 = 4.02e^(-06) MPa. These results indicated that the resistance to mechanical compression test of ironwood tree was greater than matoa tree. However, when it was seen based on the perspective of the impact on the environment, Matoa tree has environmentally friendly properties that are effective and efficient. This is supported by the nature of the matoa tree which is easy to cultivate and its roots do not damage other plants.

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Introduction

Matoa or Taun is a fruit plant that is the identity of Papua flora, which is spread in almost every area, including: the Seko land (Jayapura), Wondoswaar-Weoswar Island, Anjai Kebar, Warmare, Armina-Bintuni, Ransiki, Pami-Nuni (Manokwari), Samabusa-Nabire, and the island of Yapen.[1] Matoa is known by various names, such as Kasai (North Kalimantan, Malaysia, Indonesia), Malugai (Philippines), and Taun (Papua New Guinea). While the regional names are Kasai, Kongkir, Kungkil, Ganggo, Lauteneng, Pakam (Sumatra); Galunggung, Jampango, Kasei, Landur (Kalimantan); Kase, Landung, Nautu, Laughter, Wusel (Sulawesi); Jagir, Leungsir, Sapen (Java); Hatobu, Matoa, Motoa, Loto, Ngaa, Tawan (Maluku); Iseh, Kauna, Keba, Maa, Muni (Nusa Tenggara); Ihi, Mendek, Mohui, Senai, Laughter, Tawang (Papua).[2]

Matoa tree is known to have sweet fruit, thus the fruit can be consumed. Besides that, matoa has other benefits, matoa leaf litter is used as mulch,[3] matoa bark can be used as fabric dye.[4] Matoa is also used in the treatment of several diseases. Matoa bark is used as an antibacterial and antioxidant.[5-6] Since matoa has many benefits provided, these plants need to be preserved.[7]

In addition to these known benefits, matoa tree has also been used for its wood for a long time. Red matoa tree wood is a type of wood that has characteristics. Matoa wood is famous for its sturdy fibers and has good mechanical properties compared to other types of wood, especially for timber tree species in the tropics.[8] This is supported by the existence of unique tree roots, which have a taproot but the branches do not interfere with other plants in the vicinity. It is in contrast to the taproot owned by the mango tree.

Fig. 1: Utilization of matoa wood by the people of West Papua

In Eastern Indonesia, especially West Papua, there are many uses of natural composite materials. This is due to the natural conditions that support it. Many abundant natural resources are still untouched. Most of these natural resources are used as foundation materials for residents' houses, for example natural composites of matoa tree wood. In addition to the use of matoa tree wood as a foundation, it is also used as household furniture as shown in Figure 1.

The foundation of a house is very important for a building, because it has the main function to support the load of the building above it and pass it on to the soil at the bottom of a building. In designing the foundation, one has to pay attention to the details. There are various types of foundations for a building, one of them is a wooden foundation. The wooden foundation was chosen because the community wanted to maintain local wisdom and abundant natural wood resources.

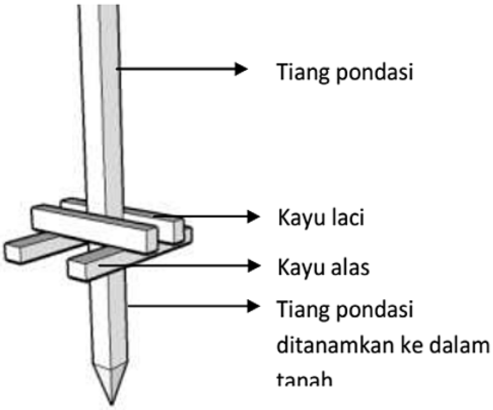


Fig. 2: Illustration of commonly used foundation designs[9]

People of West Papua are still strong in their local wisdom, the foundation design of the house still used natural composite materials as shown in Figure 1. The wooden foundation design has various forms, the shape of the pile foundation is the form commonly used by the community. Illustration of the design of the pile foundation used, as shown in Figure 2.

The foundation design is also widely used in other areas such as in South Kalimantan,[10-11] West Kalimantan,[9-12] and East Kalimantan.[13] The design was chosen because, the design is simple, appropriate with the surrounding area, and does not support heavy building loads. In addition, there are contours of swamp land (soft clay) and peat soil. Therefore, the pile foundation system was chosen since it is very adaptive to natural conditions.

Nowadays, environmentally friendly natural composite materials are very hard to find. Moreover, many synthetic composite materials were created to replace them.[14] In terms of physical strength, natural composites are not inferior to synthetic composite materials. Many applications of natural composite materials, but some of them still use a mixture of synthetic polymers. This is because the number of natural composites is limited. Examples of applications of these mixed natural composites include gear shift knobs,[15-16] various automotive parts,[17-20] and so on.

However, most of the natural wood composite materials used in building structures include reinforced soil bricks,[21] construction materials,[22] and building structural materials.[23]

Commonly, to obtain the value of the mechanical strength of natural wood composites, it used experimental methods.[24-32] In this study, a numerical method is used to obtain the value. Finite Element Methods (FEM) was chosen because it is an easy-to-use method. The numerical methods commonly used are the finite element method[33-44] and the limit equilibrium method.[45]

FEM can also be used to analyze the mechanical strength of wood-plastic composite materials,[46] compressive, buckling strength of old wood reinforced with CFRP strips,[30] Modeling of prestressed Glulam beams with compressed wood,[47] and Modeling of modified foundation from dowel installation at the glulam joint.[25]

The finite element method is a numerical procedure that can be used to find a solution to most engineering problems involving stress, heat transfer, electromagnetic and fluid flow analysis. It contains many complex forms of domain problems which can be solved easily.[48]

In general, the finite element method (for some elements) is defined as:

$$[K]T=f \quad ...(1)$$

where [K] is the matrix condition, or it can also be elaborated as:

$$[\mathbf{K}] = K_{ij} = \int_{\Omega} \left[K_x \frac{\partial N_i}{\partial x}\frac{\partial N_i}{\partial x} + \frac{\partial N_i}{\partial y}\frac{\partial N_i}{\partial y} d\Omega \right] \quad ...(2)$$

While N_i and N_j are the shape functions of the Moving Least Squares (MLS) row i and column j, respectively, T is a vector that describes nodal displacement and f is a vector that describes nodal forces and external forces, or it can also be described as:

$$\boldsymbol{f} = F_i = \int_{\Omega} Q(x,y) N_i d\Omega + \int_{\Gamma} \bar{q} N_i d\Gamma \quad ...(3)$$

The design of ironwood natural composites is presented in this study to determine which natural composite materials are best applied to the people of West Papua. The design is taken from several literatures and direct field reviews. In the literature, the nature and design of retaining walls are determined. All geometric designs were completed using numerical methods. Due to the limited data bank of the mechanical properties of matoa and ironwood, the results obtained can contribute positively to the community.

Experimental and Procedures

Analyzed Pile Foundation

Figure 3 showed the design analysis of pile foundations. This design is used on both matoa and ironwood types. The size and design of the test samples followed the literature of ASTM D-143 (Standard Test Methods for Small Clear Specimens of Timber). The design was used because it is also in accordance with field conditions. The design consists of a height and a width of 200 mm and 50 mm, respectively. The design was subjected to a mechanical compression test to determine its strength.

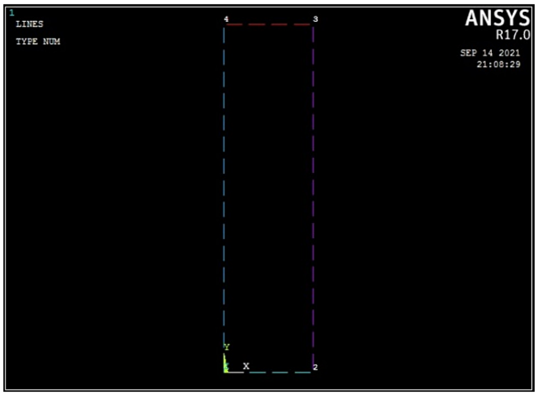


Fig. 3: Tested wooden foundation design according to ASTM D-143

Numerical Models

In this study, all retaining walls were modelled using Ansys 17.0 software running on the ASUS A451L Core i5 RAM 12 GB computer. Material properties and geometry were taken from various literature [8,50] and the number of finite elements was determined by software. The calculation used in this study is a simple calculation. For Figure 4 shows, divided into three types having different number of finite elements, A1 64 elements, A2 256 elements and A3 1024 elements and Figure 5 shows, divided into three types having different number of finite elements, B1 64 elements, B2 256 elements and B3 1024 elements.

The two models have boundary conditions according to literature with the lower boundary condition considered constant. The compressive strength given was based on the literature. The results obtained are then compared in order to obtain the safety factor value of which retaining wall is the best.

Results and Discussion

According to the results of numerical analysis, a map of the displacement distribution, and stress distribution in each of the retaining wall geometries, it can be seen that foundation structure tested horizontal and vertical displacements were well

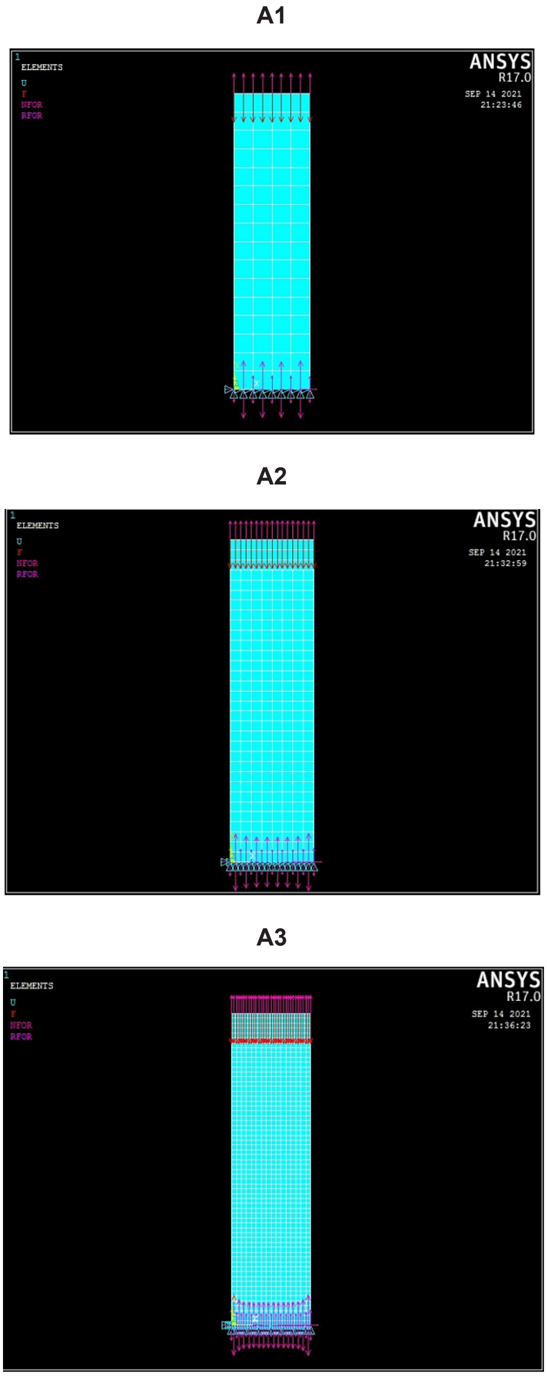
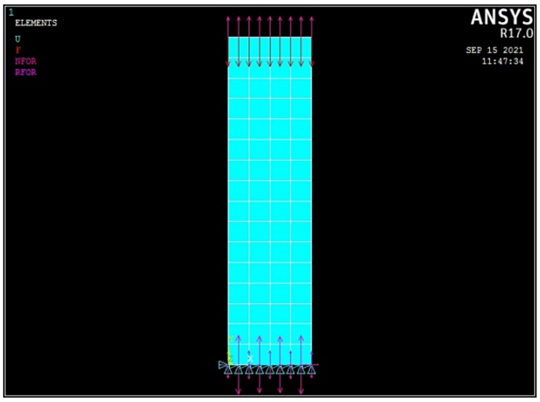


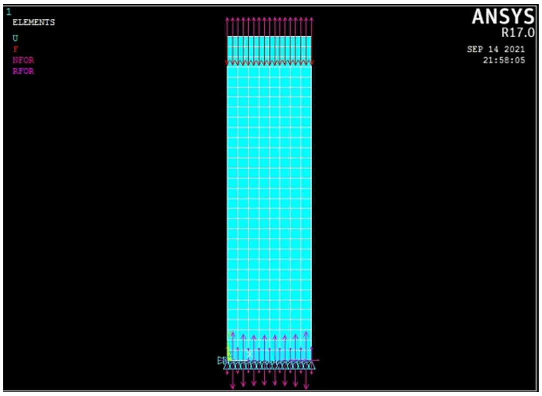
Fig. 4: Design of boundary conditions on A1, A2, and A3

distributed in each geometry presented. Each stress distribution map generated by geometries 1 and 2 was shown in Figures 6 and 7.

A1



A2



A3

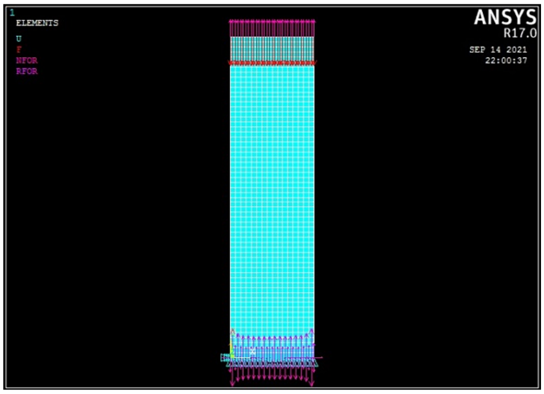
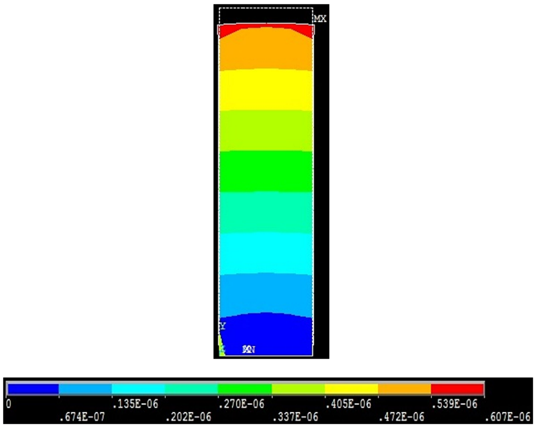
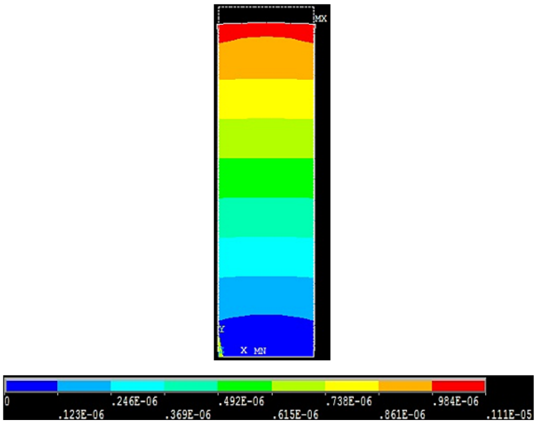


Fig. 5: Design boundary conditions on B1, B2, and B3





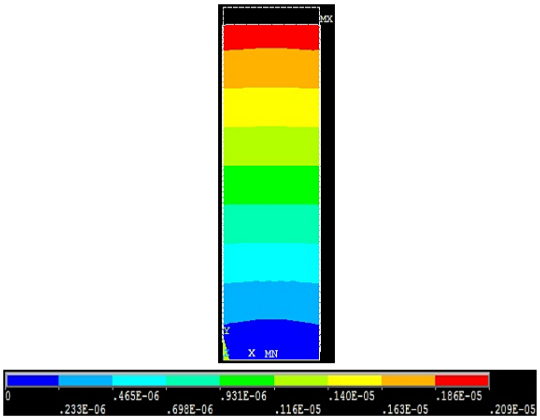


Fig. 6: Pile foundation contours A1, A2, and A3

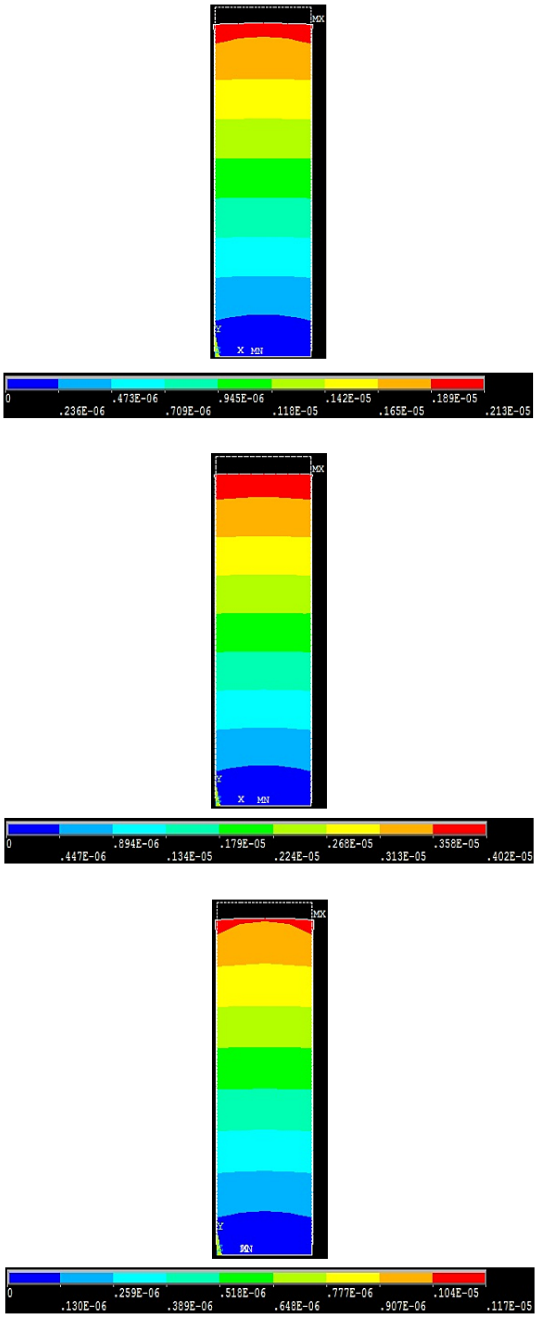


Fig. 7: Contour of pile foundation B1, B2, and B3

Figure 8. showed the magnitude of the stress in each geometry. There were three repetitions for each model. The maximum values obtained by A3 and B3 for each of these geometries were 2.09e-6 MPa and 4.02e-6 MPa. Then, A2 and B2 were 1.11e-6 MPa and 2.13e-6 MPa. Furthermore, for A1 and B1 these geometries were respectively 6.07e-7 MPa and 1.17e-6 MPa. Based on these results, it is known that the number of elements given to each geometry greatly affects the resulting value. The more element values, the higher the resulting calculation value. Therefore, the number of elements greatly affects the number of calculations when applying numerical methods. In addition, the comparison design presented is also very influential.

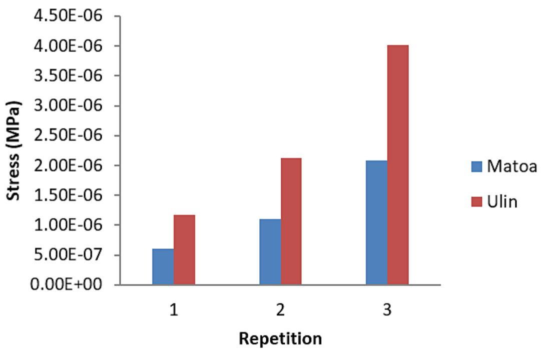


Fig. 8: Stress value at each repetition

Based on the calculation results, ironwood has a stress yield that increases with the increase in the number of elements. B3 has 1024 elements, which was the highest number compared to B2 and B1 which have 256 elements and 64 elements, respectively. This was due to the large number of elements in B3.

The same result was also experienced by A3. The A3 sample has a total of 1024 elements. This number was more than A2 and A1 which have 256 elements and 64 elements. This was due to the large number of elements in A3.

Based on numerical calculations, it is known that the safety factor generated by the model is very large in the ironwood model. Ironwood is an alternative foundation material for houses in West Papua, because the ironwood model has a better safety factor than the matoa wood model. Another reason is because the ironwood model has material properties that are inherent to the surrounding environment compared to the matoa wood model.

From the two models, the ironwood sample has a good stress distribution value based on the results of numerical calculations. Ironwood samples have very small shift and stress values compared to matoa wood. This showed that the ironwood samples tested have good mechanical properties of the material when applied to the surrounding environment compared to matoa wood. Ironwood was known for its mechanical strength. However, this tree was widely spread in Kalimantan. This tree was separated from other trees and surrounded by a circular path of ironwood. Meanwhile, at the bottom of the tree, there was a hole in it. The type of wood from the ironwood tree was not easily weathered, both in water and on land. Due to that reason, this wood was widely used as a building material, especially for houses built on marshy land.

As for the matoa tree sample, it has less stress distribution values. However, the matoa tree was a native plant of Papua, widely spread in the forests of Papua. Generally, it grew naturally on clay-textured flat soils thus when it rained it got a bit waterlogged. By the community, this plant was often used as a fruit with a mixed taste of rambutan, longan and rambutan. It belonged to the rambutan family (Sapindaceae). However, if needed, the wood will be used as a building material, especially for residents' houses.

The harvest period for transplanted matoa trees will usually produce fruit at the age of 4 years, if matoa cultivation from seeds will take 6 years to bear fruit. Matoa fruit is ready to be harvested after 2 months from starting to flower. If used as wood, the matoa tree takes 10 years to be ready for use. Unlike the ironwood tree, ironwood seed germination took a long time, about 6-12 months with a relatively low percentage of success. Moreover, the fruit production per tree was generally low. Besides that, when using ironwood wood, shipping costs were expensive since the tree was only scattered in the forests of Kalimantan. Hence, the alternative was matoa tree wood.

The force vectors generated by each model supported the values resulting from the shift and stress distributions. Figure 9 showed the style vectors of each model for matoa and ironwood. From the force vector, it was known that each geometry got a force that was evenly distributed on each side. When compared from the two models, it can be seen that the ironwood model has a good style vector. The direction of the force vector received by the ironwood model was still mostly perpendicular to the bottom, compared to the matoa wood model where the direction of the force vector has begun to bend. According to these results, the ironwood model was suitable if applied to the foundation of residents' houses. It was due to the ironwood model has compatible material properties when applied to the area, compared to the matoa wood model which experienced material degradation when applied. However, ironwood resources were not found in the West Papua. This was what hinders the use of ironwood as the foundation of people's houses, compared to matoa wood which was widely available in the West Papua region. In addition, it was easy to cultivate and many benefits provided to the surrounding community.

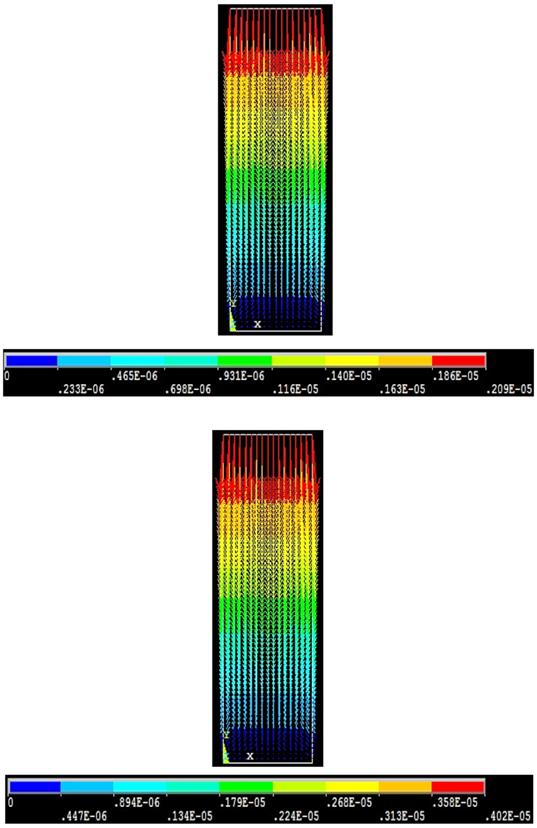


Fig. 9: The pile foundation style vector of all samples

Conclusion

Based on the research that has conducted, matoa tree wood composite is suitable if used as a house foundation. The results obtained showed that the resistance to mechanical compression test of ironwood composite was greater than that of matoa wood. The results obtained are matoa wood and ironwood, respectively A1 = 6.07e-07 MPa, A2 = 1.11e-06 MPa, and A3 = 2.09e-06 MPa, and B1 = 1.17e -06 MPa, B2 = 2.13e-06 MPa, and B3 = 4.02e-06 MPa. However, when it was seen from the perspective of the impact on the environment, matoa tree has environmentally friendly properties that are effective and efficient. This is supported by the nature of the matoa tree which is easy to cultivate and its roots do not damage other plants.

Generally, regarding the results of grafting, harvesting can be performed after 4 years from the time of grafting. In contrast to ironwood trees, ironwood seed germination takes a long time of about 6-12 months with a relatively low percentage of success. In addition, the growth rate of ironwood trees tends to be slow, it was only growing an average of 0.0058 dm per year. Thus, it is considered less economical to cultivate it as a plant on productive land. Therefore, matoa tree wood is an appropriate material if it is used as a house foundation material.

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Conflict of interest

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